Analysis of the evolution of the reflectivity of sediments settled during the 1996 flood in the Saguenay Fjord, using the SIMRAD EM1000 multibeam sonar.

Thierry SCHMITT[1], Jacques LOCAT[1], Edouard KAMMERER [2], Phillip HILL[3], Bernard LONG[4], John HUGHES CLARKE[2] and Roger URGELES[1].*

[1] Département de Géologie et de Génie Géologique, Pavillon Pouliot,Université Laval,G1K 7P4 Sainte-Foy, QUEBEC
[2] Ocean Mapping Group, University of New Brunswick, Fredericton, New Brunswick
[3] Université du Québec à Rimouski,Québec
[4]Institut National de la Recherche Scientifique, Québec

Abstract

As part of a multidisciplinary project, mainly lead by the University Laval, with other Canadian universities on the analisys of the consequences of the 1996 flood in the Saguenay Fjord (Province of Quebec), multibeam data were acquired, with a Simrad EM1000. The area of interest is located near the cities of Chicoutimi and Ville de La Baie. This same area has been surveyed three times, in 1993, 1997, 1999.

As the two first surveys (1993 and 1997) were compared, major differences in the reflectivity of the sediments were revealed. After the flood (in 1997), the distribution of areas with less reflectivity were located principally along the axis of the fjord. Then, the signals seems to penetrate more in the freshly deposited layers, which have a less densely pacted structure. The hypothesis we want to discuss in this paper, is that these areas with low reflectivity are linked with the freshly deposited sediments. If this assumption is right, the backscatter is expected to increase with the time since the water content will decrease as consolidation progresses.

Thus the objective of this research work is to : (1) study the geographical distribution of the backscatter (i.e. the ratio between the received and the emitted energy of the acoustical wave, turn in dB), (2) find a link between the backscatter and the water content of grab samples collected in 1999, just one month after the last survey (almost 184 samples widely distributed across the study area).

The preliminary results of this study, will show that the backscatter changes can be related to the flood event of 1996. But it will also show that an useful model describing the interaction of the acoustic wave and the sediment properties has still to be clarified in order to positively map the extent and several consequences of the 1996 flood.

Résumé

Dans le cadre d'un projet multidisciplinaire, mené par l'Université Laval en association avec plusieurs universités canadiennes, suite au déluge du Saguenay, des sondages multi-faisceaux ont été effectués à l'aide des EM1000. Ces données ont été acquises dans la région de La Baie des Ha! Ha! et du Bras Nord, à proximité de Chicoutimi, et cela sur trois années différentes 1993,1997 et 1999.

L'analyse comparative des données de 1993 et de 1997 révèlent des différences majeures de réflectivité des sédiments. On constate, qu'après le déluge, le signal est moins réfléchi dans la région axiale, et cela sur une dizaine de kilomètres par rapport aux lieux de décharges des rivières ayant été en crue. Il est aussi évident que la rugosité du fond marin influence cette mesure. L'hypothèse à vérifier est la suivante : les zones de faible retour de l'onde acoustique représentent les zones accumulées récemment et donc gorgées d'eau. La réflectivié de ces zones devrait augmenter avec le temps suite à la consolidation des sédiments et à l'action de la faune par la bioturbation. En effet, ces phénomènes impliquent une réduction de la teneur en eau et donc une augmentation de la densité.

Les objectifs de cet article sont les suivants : (1) étudier la distribution géographique de la réflectivité des sédiments (le rapport entre énergie reçue et énergie émise de l'onde émise par chaque faisceau du sonar, transformé en décibels), et (2) déterminer un lien avec la teneur en eau d'échantillons pris dans la région en question en 1999 au même moment que la réalisation des levés multi-faisceaux (environ 184 échantillons largement espacés et représentatifs de la zone d'étude).

Les résultats préliminaires de cette étude montreront que les variations dans la mesure de la réflectivité peuvent être lier à la crue de 1996. Cependant cet article mettra aussi en évidence l'importance de trouver un model décrivant plus clairement les interactions entre l'onde acoustique et les propriétés du sol marin. Alors il sera possible de décrire clairement l'extension des sédiments provenant du déluge de 1996.

Introduction.

In July 1993 a SIMRAD EM1000 (on board of the C.H.S. Vessel Frederick G. Creed) multibeam survey was conducted in the upper part of the Saguenay Fjord near the cities of La Baie and Chicoutimi. In 1996, a flood occurred in the surveyed area. In 1997 a collocated survey was done, in order to map the changes between each of the surveys. A comparative analysis was done by Kammerer et al. (1998), which suggested that the extent of the flood layer could be measured by the backscatter data. Since density is one of the main factors influencing the backscatter intensity, we hypothesized that backscatter would increase as the flood layer would consolidate with time. To verify this hypothesis another SIMRAD EM1000 survey was conducted in the same area in 1999 with a sampling campaign.

This paper, after a review of the methodology, will present a preliminary analysis of the backscatter data acquired in 1993, 1997 and 1999. Hence, it provide an opportunity to evaluate the potential of the SIMRAD EM1000 backscatter measurement as a tool for monitoring the extent and the evolution of a fine-grained capping layer.

Location.

The Saguenay Fjord region is located in the Province of Quebec. It extends over a length of about 80km and a width of 1 to 6km, before reaching the Saint-Lawrence River (Fig. 1).

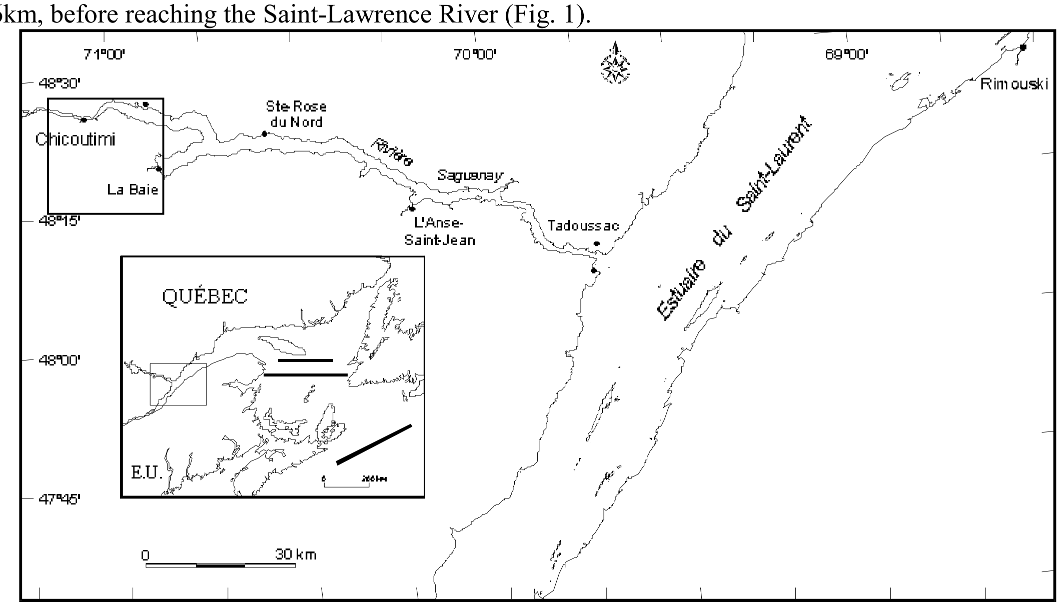


Figure 1. The area of study is delimited by 70°55'W 48°27'N / 48°20'N 70°40'W and can be seen as the square surounding the city of La Baie and Chicoutimi.

In the area of interest, bathymetry ranges from 0 to 200m (Fig. 2). Its typical morphology consists of steep slopes and a relatively flat basin floor. There are many effluents into the fjord, such as the Rivière à Mars, the rivière Saguenay and the Rivière des Ha! Ha! They have usually a low sediment input.

During the flood event of July 1996, a dam on the Rivière des Ha! Ha! failed because of the extreme rainfall. This resulted in an extreme erosion rate along the river and the transport of large amounts of sediment into the Baie des Ha! Ha!, near the city of Ville de La Baie. The main sediment accumulation are located at the mouth of the major rivers where thickness could be in excess of 5m (Kammerer et al., 1998). The usual sedimentation is characterised by fine grained sediments ranging from sands to silty clays and more sandy near the rivers mouths.

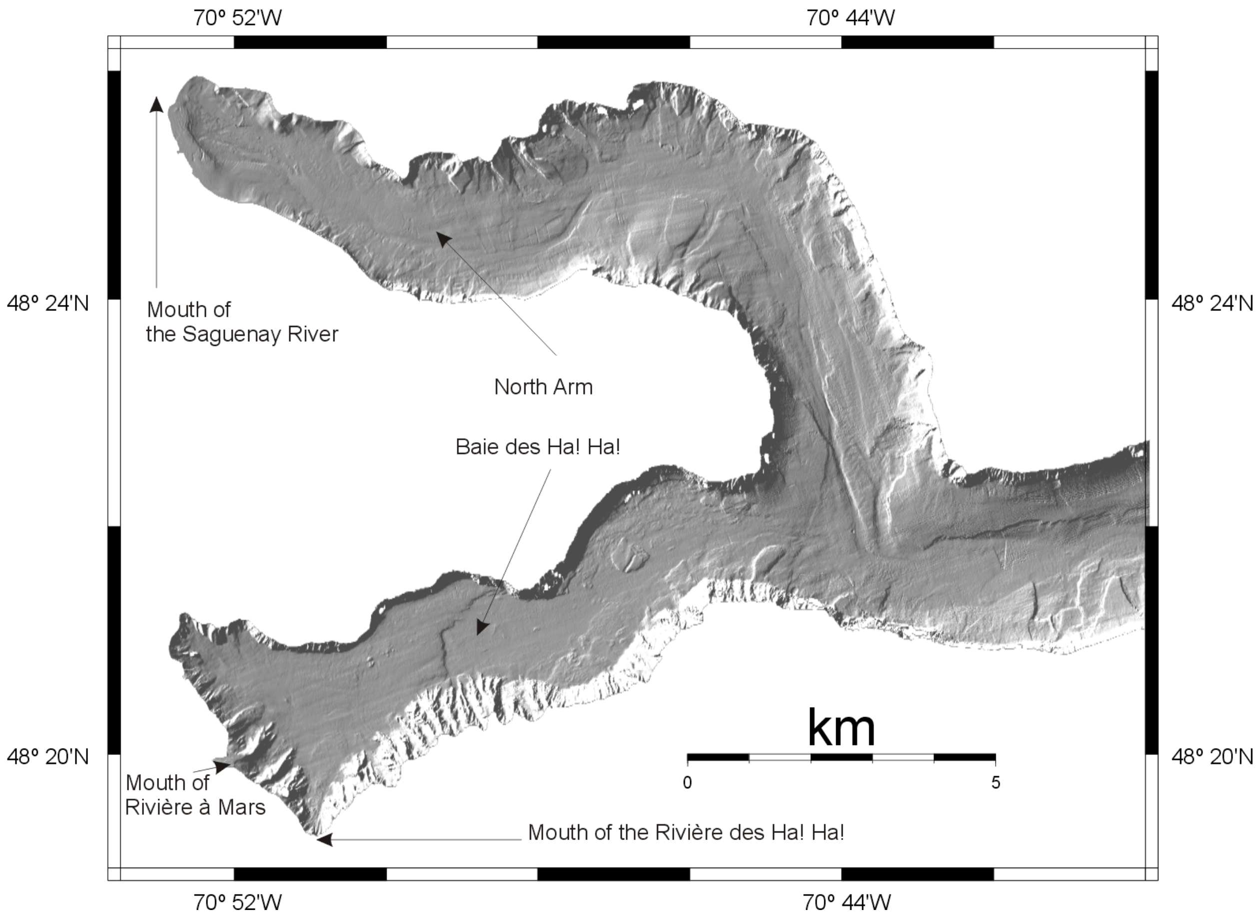


Figure 2. Sun illuminated view of the bathymetry of the area of interest.

Methodology.

Multibeam data acquisition and processing.

The multibeam hull-mounted sonar EM1000, from the SIMRAD Company has acquired all the data. The C.S.S. Frederick G. Creed EM1000 operates at a frequency of 95kHz and is valid for surveys at water depths ranging between 5 and 800m. The size of its 60 beams, covering an angle of 150 degrees, is 2.4° by 3.3°. Furthermore Differential Global Positioning System and motion sensors monitor positions and movements of the boat (pitch, yaw and roll) in order to accurately give the positions of the bathymetry and the backscatter measurements. Between 1993 and 1997 several technical changes took place on the acquisition system. A major one was the replacement of the TSS-335b motion sensor by the POS-MV after 1997. The POS-MV allows to log data while the boat is turning or is navigating in movements of high amplitudes. With this kind of upgrade, there were less erroneous data and less noise.

Usually, data were collected at a boat speed of about 12 knots and at a rate of 0.6 to 1.1 pulse per second. Also as the propagation of the sonic wave is strongly influenced by the density of the water, several Sound Velocity Profiles were measured. Tides levels were read at the Port Alfred Harbour and used for processing. In each sector of the study area a navigation baseline was selected along the axis of the fjord, an offset between each line was chosen according to water depth. Usually an overlap of 100% between swaths was used.

More than collecting the time series for the bathymetry, the EM1000 Sonar also measures the backscatter strength, which is more useful for the purpose of this paper. This value is saved as a dimensionless number, which represents the ratio of the backscatter intensity as a function of the incident power per unit area of the seafloor per each beam.

On board of the C.S.S. Frederick G.Creed, the EM1000 software MERLIN corrects the amplitude time series for gain changes, propagation losses, predicted beam patterns and for the lited area (with the simplifying assumptions of a flat seafloor and Lambertian scattering). (Hammerstad, 1994)

On earth, another treatment is required. Data must be firstly processed in terms of bathymetric data. To say it short, each transducer for each beam gives a time value. As the water velocity and the angle of the beam is known it is straightforward to calculate the distance between the hull of the boat and the seafloor. Bathymetric data are then gridded into an area using a nearest neighbour interpolation. In our case the grid spacing was 15m.

To obtain real backscatter, which may be linked with the type of the sediments but not the topography, bathymetric data must be known to evaluate the slopes. As the grazing angle is continuously changing, knowing the real seafloor slopes and applying empirically derived beam-pattern corrections allow to produce a quantitative estimate of the seafloor backscatter across the swath.

Sampling campaign.

During the summer of 1999, 184 grab samples have been collected on the floor of the fjord with a “Shipek” sampler. This is an half cylinder of 15 cm deep which can collect almost $0.01m^3$ of sediments. The sediment is disturbed but it keeps more or less the original lithology. A spacing of ~500m have been chosen between each samples. But due to the DGPS accuracy, and the angle of the cable while the samplers was going to the bottom, the location of the sample is not precise to more than 10 to 25m. On board a quick textural and biological description of the sediment was done and two sub-samples of material were taken and put into airtight bottles.

Results

Backscatter data.

Raw backscatter mosaics were processed with the method described above. In practice, it should be feasible to directly compare the three surveys but because of the electronic hardware was significantly modified, while

we can monitor relative changes of less than 2dB within a single survey, we cannot be confident in the absolute values of the backscatter strength to better than about ~5dB in between differente surveys. In order to counterbalance this, it was necessary to normalise the backscatter values for each survey. It was done the same calibration as in Kammerer et al. (1998). The most distal part of the surveyed area, is supposed to have a backscatter that did not change much, because a very small amount of sedimentation occurs in this place. The mean value of the 1993 backscatter values from this area, and the following surveys were normalised.

Figure 3 shows that the general trend observed in the three surveys, in terms of temporal changes, is a variation of the backscatter with minimal values in 1997, just one year after the flood. The measurement of the scattering strength is directly linked to physical properties of the water and as well as those of the sea floor (Urick, 1975). Water parameters are supposed to be taken into account in the processing by the calibration with frequent SVP. The measured values of the backscatter are mainly dependent of the (1) the grazing angle of the beam (θ), (2) the seafloor roughness (r), (3) the porosity of the sediment (P), (4) its density (ρ), (5) the attenuation of the amplitude of the sound wave in the soil (L), (6) the frequency of the sound wave (f), (7) the compression wave velocity in the seafloor compared to the one in the water column (υ).

Numerous and sometimes contradicting models have been developed for interpreting backscatter data such as Lambert model, perturbation theory, composite roughness model and synthetic model (Blondel and Pouliquen, 1996). To sum up this parameters we can write this relation:

$$BS = \mathrm{f}(\theta, \mathrm{r}, \mathrm{P}, \rho, L, f, \upsilon) \quad [1]$$

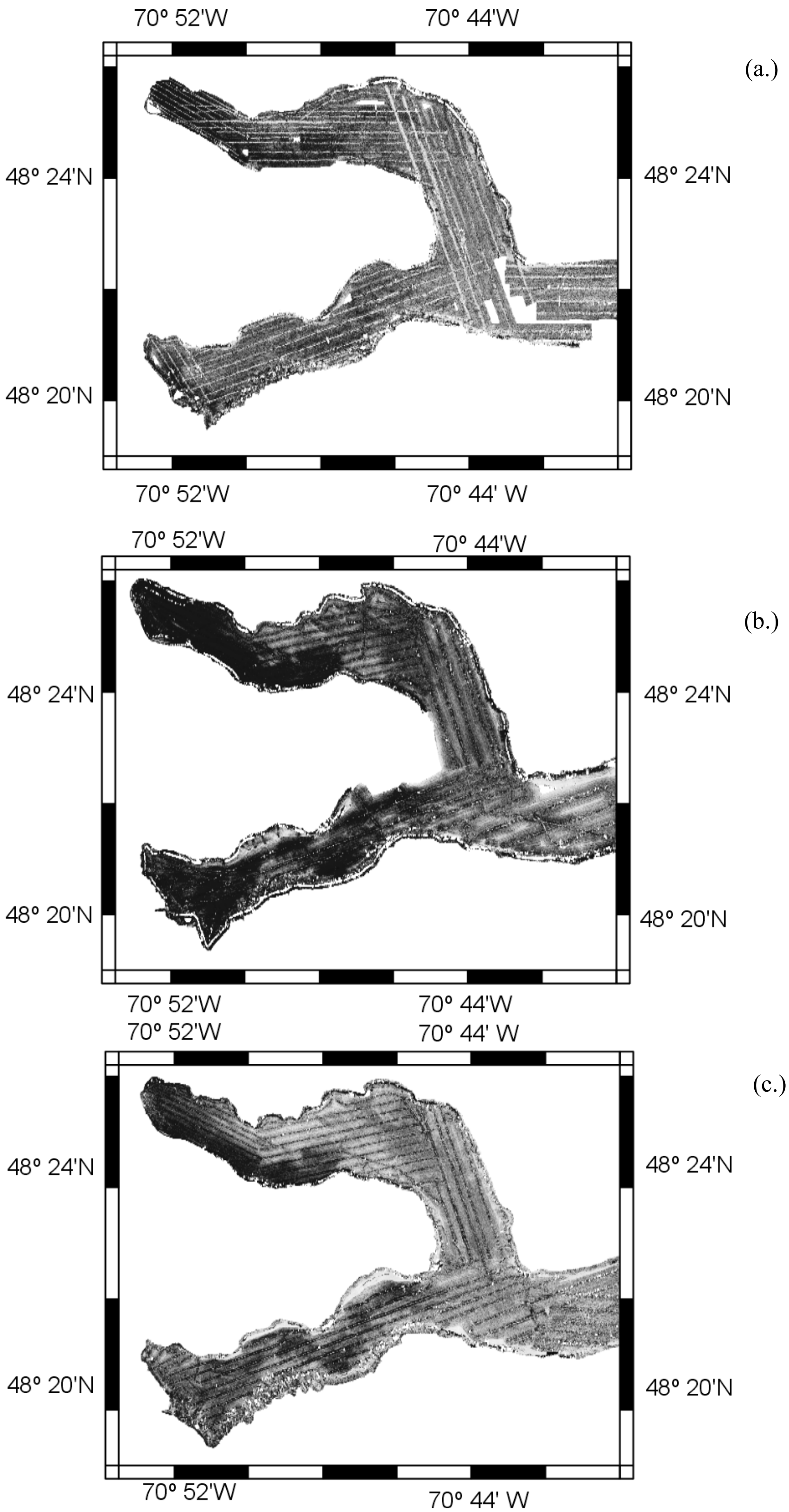


Figure 3. Temporal changes of the backscatter on the three surveys: (a) 1993, (b) 1997, (c) 1999.

Temporal changes.

Three typical areas can be observed in the different surveys. The first one has a high backscatter (bright area) and is located in the lower part of the Bras Nord, and also down the junction of the two arms. There, it is supposed that sedimentation rate are law. In consequence, the backscatter should not have changed very much between the three different surveys. The second type area is a low backscatter one. This area is situated near the mouth of the different rivers draining into the fjord (i.e., the Saguenay River in the Bras Nord, the Rivière à Mars and the the Rivière des Ha! Ha! in the upper part of the Baie des Ha! Ha!). The extension of this area is variable on the 3 surveys and it is believed to be a good indicator of the extension of the flood in space and in time. Finally a strongly heterogenous area is located along the south part of the upper Baie des Ha! Ha!, which is probably due to a strongly changing topography.

Before the flood, in 1993, figure 3.a shows that low backscatter values are located mainly in the Bras Nord, near the mouth of the Saguenay River and along the south shore of the arm. It is also possible to see another dark area along the west coast of the Baie des Ha! Ha!, where small amounts of sediment from the river are continuously deposited.

In 1997, just after the flood, the contrast between low and high backscatter areas is even more manifest. The main changes between the two years concerns the extensions of the low backscatter type area (dark). A low backscatter area is noticeable near the mouth of the river and along the axis of the Baie des Ha ! Ha !, on a distance of about 10 km, becoming brighter and brighter away from the river mouth. The major events of the flood of 1996 were located in La Baie des Ha ! Ha !. This suggests a correlation of the backscatter with the 1996 event since in this place the deposition of new materials reached a thickness of 5m.

Comparing the two previous surveys and the one of 1999, it is clear that the different areas of low backscatter are still located almost at the same place, but a diminution of their extension is also obvious. We can therefore say that backscatter intensity tends to return to the 1993 values, which we consider to be the reference level. However, mainly in the Baie des Ha ! Ha ! the extension of the low backscatter area along the axis of the fjord is still more important than in 1993.

Grab samples results and Water content distribution.

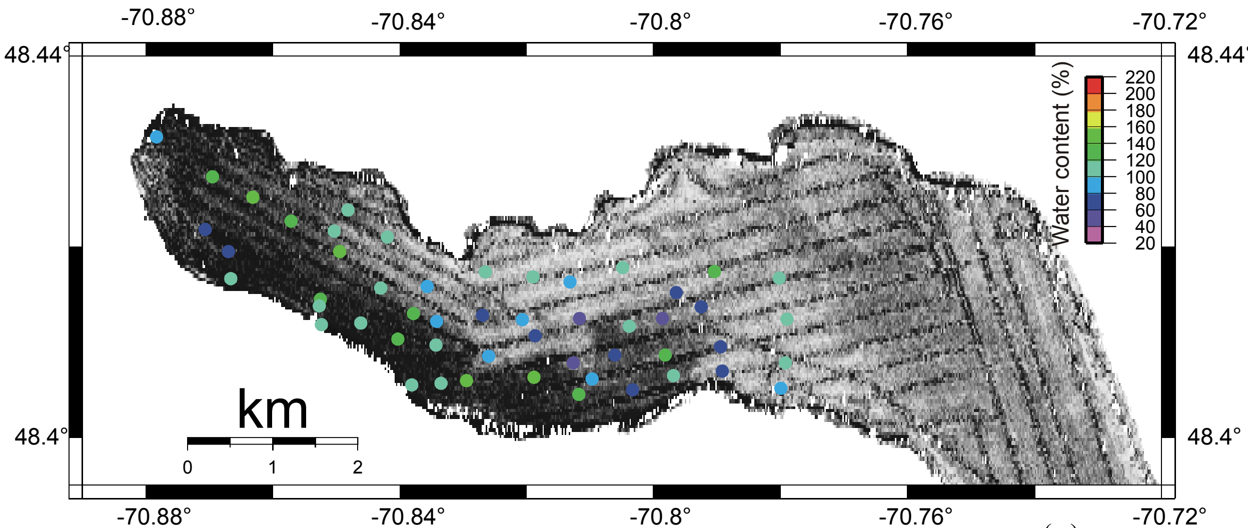
Samples were taken in the upper part of the Bras Nord and in the Baie des Ha! Ha!, at distances 50m in excess from the shoreline. The collected samples are mostly clay to clayey silt sediments. Generally, water content ranges between as low as 20% to 220% of the dry mass of the sample, and is thus very variable. Near the mouth of the Rivière des Ha! Ha! and the Rivière à Mars, where the 1996 deposits are thickest, the sediments become silty to sandy, and the sampler was not able to collect anything. In the rare case where some material was taken in this sandy area, the water tends to drain while the sampler is put on the deck, and consequently the water content is very low and not representative of the relative moisture of the sediment.

In the Bras Nord, the maximum water content is 142% in the upper part of the area, and the minimum value is 40%. A general trend shows that it declines with the distance from the mouth of the Saguenay River. In la Baie des Ha! Ha!, the water content distribution is more variable. The upper part of the Baie des Ha! Ha!, near the mouth of the two rivers, sandy sediments can be found and values as low as 28% of the dry mass have been measured. Downstream, in the lower part of the Baie des Ha! Ha!, the water content ranges between 80% to 200%,and seems to be more characteristic of muddy sediments water content.

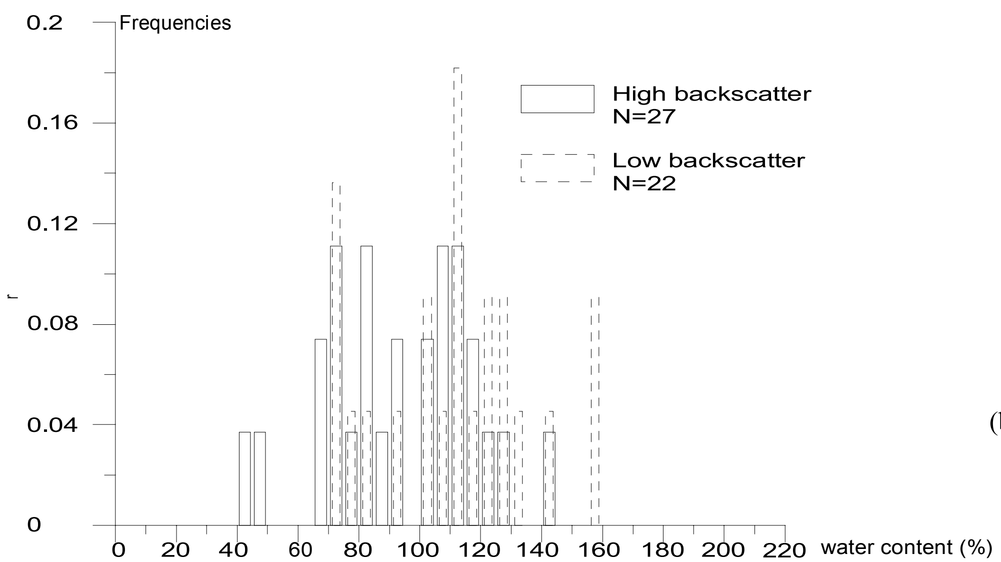
The three sets of illustrations on the next pages show 3 distinctive areas in which values of water content were correlated to backscatter measurement. The idea was to choose an area of ~30 m around the point where the sample was taken, and average the backscatter measurement.

♦ The Bras Nord

A clear backscatter contrast can be appreciated. Figure 4.b shows the water content distribution in low and high backscatter areas. The distribution is more or less gaussian for both areas. Frequencies of water content in the low backscatter class are between 70% and 160%, whereas water content distribution in the high backscatter class is in the range 40% to 145%. Furthermore a little translation between the two gaussian curves can be seen.



(a.)



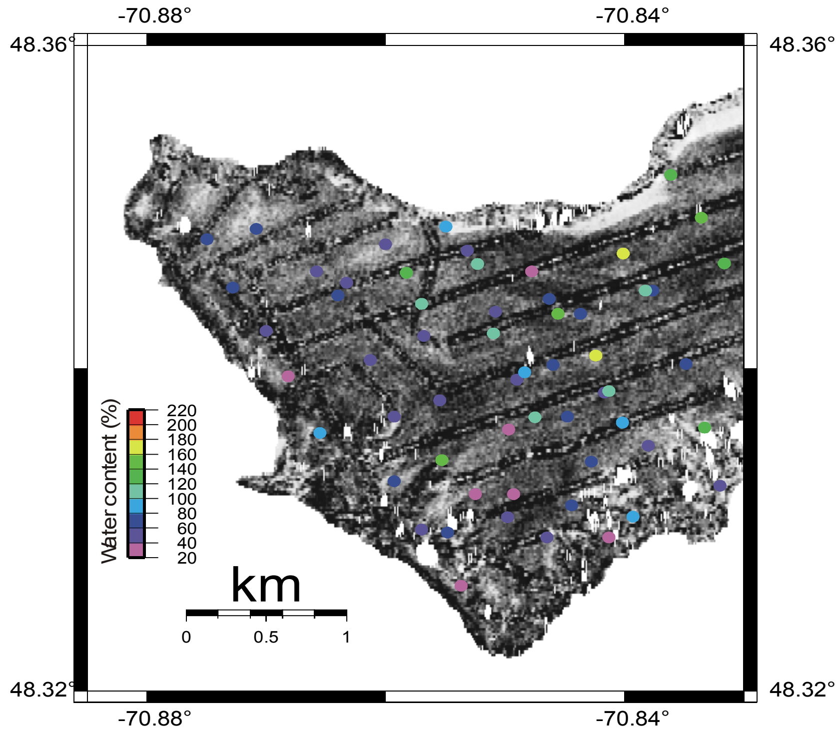
(b.)

Figure 4. (a) Backscatter data and water content measurement in 1999, (b) : water content distribution of the frequencies classified in high and low backscatter classes.

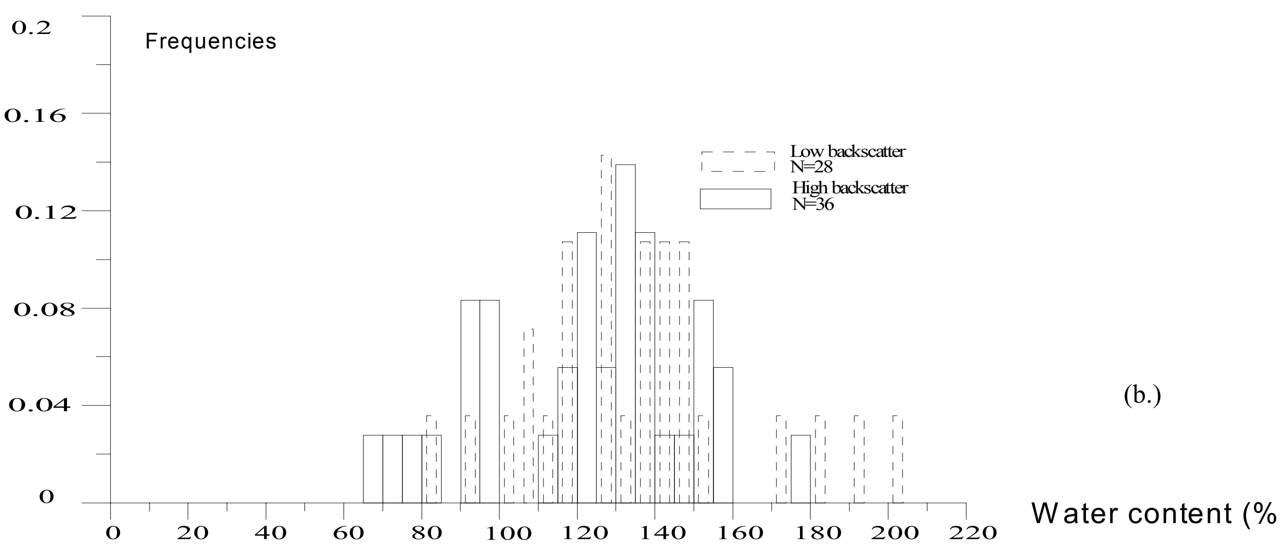
♦ The upper part of the Baie des Ha! Ha!

The area of La Baie des Ha! Ha! was divided into two parts mainly because of the extenesion of the sediments deposited by the flood. As in the previous area, two classes are defined, according to the backscatter intensity. The division, is more problematic than in the Bras Nord because the contrast is not as clear. Indeed, the backscatter is quite high in this region which may be due to the fact that it was the place where saturated sediments settled after the flood.

Two main areas with low backscatter are visible. The first is located in the north–east part of the figure 5.a. Here a small river, the Rivière à Philipe, has a low water input. The other area is located along the south and western shore. Bathymetric surveys show that this area has gullied morphology, and thus higher scattering may be due to a meso-scale roughness effect. Fig 5.b, in the same maner as fig 4.b, shows that the water content distribution in the low backscatter area is also shifted towards the higher water content.



(a.)

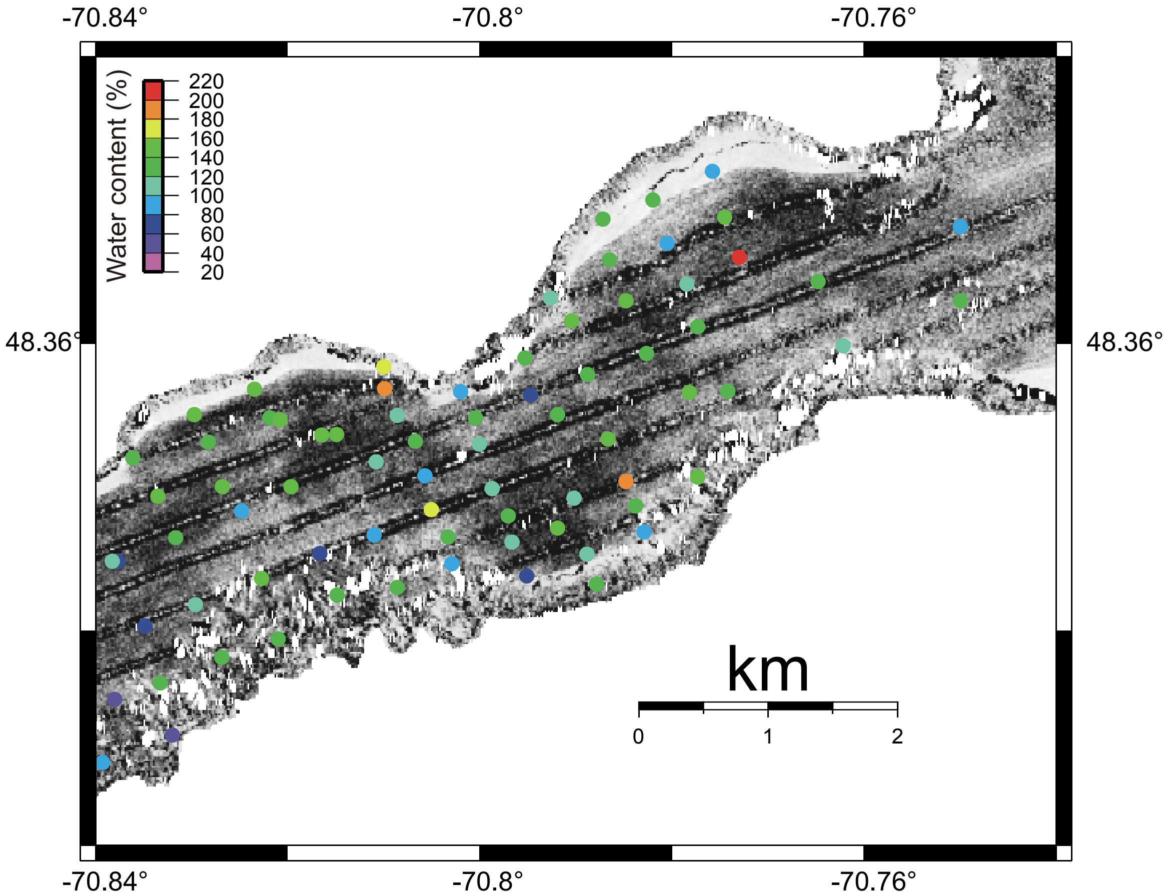


(b.)

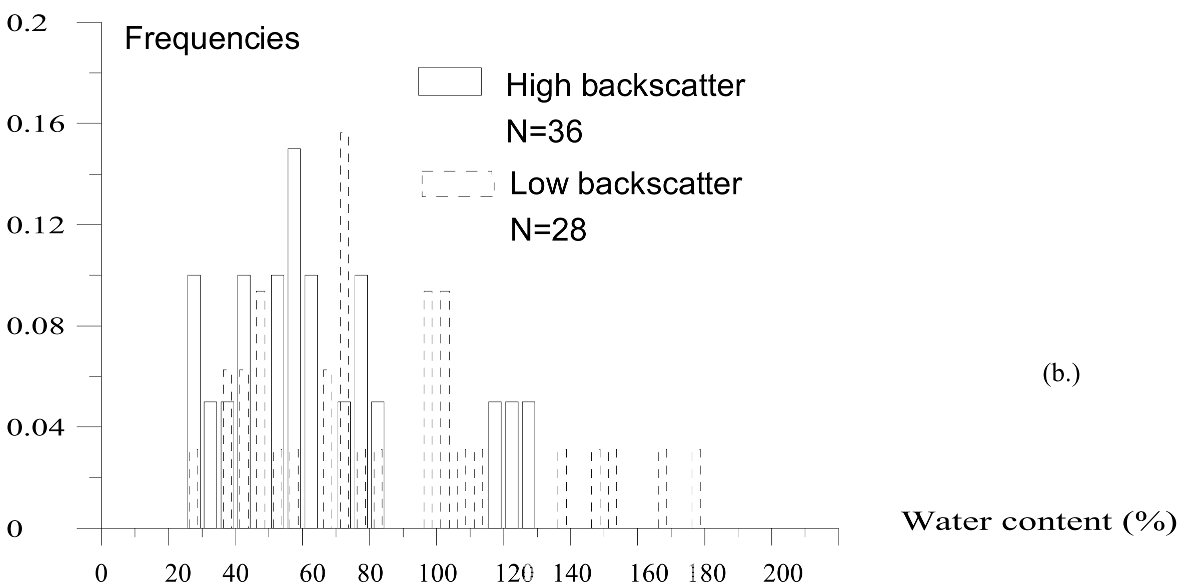
Figure 5 (a) Water content distribution in the upper part of the Baie des Ha! Ha! compared to backscatter data, (b) : distribution of the frequencies of the water content according to their class of low or high

♦ The lower part of the Baie des Ha! Ha!

The lower part of the Baie des Ha! Ha! is characterized by a low backscatter area which extends along the middle of the fjord. Since the sediments are more clayey, the water content measurement is more represantative than in the sandy areas. Figure 6.b also shows the typical shift, already seen on figures 5.b and 4.b.



(a.)



(b.)

Figure 6 (a) Water content distribution in the lower part of the Baie des Ha! Ha!, (b) : distribution of the water content frequencies classed in categories of low and high backscatter.

Discussion.

Difficulty on the comparison of the sidescan mosaic.

The major problem concers the internal calibration between the three surveys, in choosing the distal part of the fjord as a reference. We consider this approach to be acceptable because there is no significant deposit associated with the 1996 flood and since we are, for a first estimate, interseted in relative changes.

Temporal changes

Since the lowest backscatter values are observed in 1997, we hypothesize that backscatter variations are linked with the 1996 flood event (Fig. 3) shows changes in the backscatter linked with the 1996 flood event, since the lowest value of the backscatter were observed in 1997. The extent of the area of low backscatter has the same appear to vanish with the time as strength and bioturbation which conditions advance towards towards 1993 levels, since Pelletier (1999) shows that recolonisation of the seafloor by organism is increasing since 1996. In order to confirm (or not) our hypothesis a similar SIMRAD EM1000 survey is plan for 2001.

Relation between acoustic backscatter and physical parameters of the sediments.

We can see two components in the scattering (Urick, 1975). One is due to the interface between the water and the seafloor on which the acoustical wave bounces. The other component is the volume scattering, which is influenced by the physical properties of the sediments. At present the role of the latter component has been studied using the water content. There also seems to be a relationship between water content and backscatter. As mentioned above, there are several other parameters influencing the backscatter. Further investigations (i.e mean grain size measurements) will be done in order to envisage more clear liaisons between backscatter and flood consequencies description.

Although we have not yet completed our detailed analysis of the role of other parameters, we would like to comment on the potential contribution of the roughness which is known to strongly influence acoustic response of the seafloor.The roughness is principally related to the meso-scale (meter) and the micro-scale (centimetre) morphology of the surface of the seafloor (Jackson, 1996). Hence, a high roughness will induce diffusive scattering of the acoustical wave and then a higher backscatter than predicted from a plane surface. Along the South Shore of the Baie des Ha ! Ha !, the variability of the topography, is also visible on the backscatter map and can be directly related to topographic changes. In addition, bioturbation seems to be a major factor in influencing the bed roughness (J.A Goff et al., 1999). This parameter may explain why the 1993 data appears brigther than 1997 and 1999. The next survey will confirm (or not) the role of bioturbation on changes in the backscatter signature of the flood layer.

Conclusion.

In this paper we have studied the temporal and geographical variations of the backscatter intensity in the Saguenay Fjord. These backscatter data have been compared to water content). At this point of the study we can conclude that :

- The evolution of the overall backscatter patterns is consistant with our initial hypothesis that it should vanish as the pre 1996 conditions are restored in terms of strength and bioturbation.
- There is a correlation between water content and backscatter, but further investigations are needed in order to determine the role of other several parameters.

These preliminary conclusions will be reviewed when more information on the nature of the samples collected (i.e mean grain size) and after the next (2001) multibeam survey will be available.

Acknowledgement.

All this work could not have been done without the expertise of the crew of the NSC Frederick G. and all the scientific staff from the Canadian Hydrographic Service of Mont-Joli (Province of Québec).
The Saguenay Project, is funded by a strategic grant from the National Science And Engineering Research Council Of Canada (NSERC-CRSNG) and the society ALCAN Ltd and the Québec Ministry of Education.
Several maps have been done with the Generic Mapping Tool, developped by Pal Wessel and Walter Smith.

Bibliography.

Blondel, Ph.,Pouliquen E., and the LUSTRE'96 Science Party, (1996). Acoustic Backscatter Mechanism and Quantitative Geology of Mid-Ocean Ridges. EOS Trans. AGU.

Goff, J. A., Orange D.L., Mayer, L.A., Hughes Clarke, J.E., (1999). Detailed investigation of continental shelf morphology using a high-resolution swath sonar survey : the Eel margin, northern california. Mar. Geol.154, 255-269 .

Hammerstad, E., (1994). Backscattering and sonar image reflectivity. EM12/950/1000 Technical Note, Publication of Simrad Norge AS, Horten, Norway, 10pp.

Jackson, D.R., Briggs, K.B., Williams, K.L. And Richardson, M.D., (1996). Test of models for high frequency seafloor backscatter. IEEE Journal of Oceanic Engineering, 21,

Kammerer, E., Hughes Clarke, J.E., Locat, et al., (1998). Monitoring temporal changes in seabed morphology and composition using multibeam sonars : a case study of the 1996 Saguenay River floods. Proceedings Canadian Hydrographic Conference 1998, Victoria, 450-461.

Simrad, Simrad EM 1000 Hydrographic echo sounder, #P2415E

Urick, R. J., (1975). Principle of underwater sound. McGraw-Hill, New-York, 384 pp.